

A Graph-based Model of Object Recognition Self-Learning

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Abstract

In this paper, we study the object recognition self-learning for robots. In particular, we consider the self-learning during solution of typical tasks. We propose a graph-based model for self-learning. This model is based on the problem of monochromatic path for given set of weights. We prove that the problem is **NP**-complete. We consider an approach to solve the problem. This approach is based on an explicit reduction from the problem to the satisfiability problem.

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1 Introduction

Mobile indoor robots are extensively investigated in robotics. It should be noted that different robotics planning problems are very important. In particular, we can mention a problem of planning a typical working day for indoor service robots [1]. In many cases, intelligent robots need some modules of self-learning (see e.g. [2]). It is natural to consider modules that allow self-learning and solution of ordinal tasks in same time. In this paper, we consider a graph-based model for self-learning during solution of typical tasks.

2 The Model of Self-Learning

We assume that a mobile indoor robot during daily work performs a number of tasks. Ability to solve different tasks can be represented as a digraph. In

particular, let $G = (V, E)$ is a digraph where

$$V = \{v_1, v_2, \dots, v_n\}$$

is the set of nodes and

$$E \subseteq \{(v_i, v_j) \mid 1 \leq i \leq n, 1 \leq j \leq n\}$$

is the set of arcs. We can consider V as the set of tasks. In this case, $(v_i, v_j) \in E$ is an action, which should be performed by the robot to solve $v_j \in V$. During daily work, a robot performs some sequence of tasks, which is called a path. In this paper, we consider only simple paths.

For intelligent robot it is important to have an ability of self-learning. In particular, it is natural to consider some combination of self-learning and performing of daily tasks. For instance, we can consider a following example. A vacuum cleaner robot can observe the environment and fix some new facts during cleaning. It can be appearance of new objects in room, changes of placement of furniture, etc. After observation, the robot within a some model of self-learning can learn properties of discovered facts. We assume that each arc of a digraph G has a color. If the number of colors is restricted by an integer c , we speak about c -arc-colored digraphs. So, we can say that G is a c -arc-colored digraph where

$$C = \{1, 2, \dots, c\}$$

is the set of colors. Let E_t is set of arcs of color t where

$$E = \cup_{t=1}^c E_t.$$

We assume that the color of some arc corresponds to a capability of learning of some specified fact. Each color corresponds only one fact. In this paper, we consider monochromatic paths. We say that a path is monochromatic if all arcs in it has the same color. A monochromatic path in G corresponds to some learning process of different properties of some fact.

In this paper, we consider a problem of visual recognition self-learning during performing daily tasks for mobile indoor robots. To learn to recognize some fixed object, fact or class of objects, it is natural to schedule robot's tasks so that the robot should be able to observe an appropriate fact during performing each of these tasks. In most cases, recognition suggests learning of some fixed set of object properties. But, it is possible that a robot can not to learn some necessary property during performing some daily tasks. For instance, we can assume that the current main task of the housekeeping robot is cooking. It is natural to assume that the robot must performs this task at the kitchen. Therefore, the robot can not to learn properties of new carpet in

living room during performing the main task. So, a model should take into account not only possibility of interaction with object, but also a capability to learn this property during performing particular task.

Correspondingly, a plan of object recognition self-learning during performing daily tasks we can represent as a c -arc-colored digraph with weighted nodes. We assume that each node v of G has a weight $w(v)$ where

$$\{1, 2, \dots, R\}$$

is the set of weights of nodes. We assume that W_r is the set of all nodes of weight r , for all $1 \leq r \leq R$.

We can assume that satisfying plan of object recognition self-learning is a path with sufficient length such that all arcs of this path have the same color and all nodes have weights from given set U .

We can consider the following example. A robot should learn weights of home dishes. In particular, we can consider the following set of tasks:

1. Set the table;
2. Cook soup;
3. Wash the dishes;
4. Wash the floor on kitchen;
5. Tidy up things;
6. Run the vacuum cleaner;
7. Wash the floor on living room.

It is natural to consider the following set of arcs:

$$\begin{aligned} &\{(1, 2), (2, 1), (2, 3), (3, 2), (3, 4), (4, 3), (4, 1), (1, 4), (2, 4), \\ &(4, 2), (1, 5), (2, 5), (3, 5), (4, 5), (5, 6), (6, 7), (5, 7), (5, 1), (5, 2), \\ &(5, 3), (5, 4), (6, 1), (6, 2), (6, 3), (6, 4), (7, 1), (7, 2), (7, 3), (7, 4)\}. \end{aligned}$$

Clearly, the robot can learn properties of dishes during performing “set the table”, “cook soup”, and “wash the dishes”. However, the robot can learn weights of dishes only if it has a contact with dishes. Therefore, the robot can learn weights of dishes only during performing “set the table” and “wash the dishes”. So, to learn weights of dishes, the robot should select a sequence of tasks with nodes “set the table” and “wash the dishes”.

Now, we define the problem formally.

THE PROBLEM OF MONOCHROMATIC PATH FOR GIVEN SET OF WEIGHTS (MP):

INSTANCE: *Given c -arc-colored graph $G = (V, E)$ with $c \geq 2$, W_r , $1 < r < R$, E_t , $1 < t < m$, $U \subseteq \{1, 2, \dots, R\}$, a positive integer k .*

QUESTION: *Is there a path v_{i_1}, \dots, v_{i_p} such that*

$$\{w(v_{i_1}), \dots, w(v_{i_p})\} \subseteq U,$$

$$p \geq k,$$

$$\{(v_{i_1}, v_{i_2}), \dots, (v_{i_{p-1}}, v_{i_p})\} \subseteq E_t \text{ for some } t,$$

$$v_{i_a} \neq v_{i_b} \text{ for } a \neq b?$$

3 NP-Completeness of MP

Theorem. *MP is NP-complete.*

Proof. Clearly, we can check a correct path in a graph on nondeterministic Turing machine in polynomial time with an oracle. Thus, MP is in **NP**. To prove **NP**-hardness, we can reduce the problem of hamiltonian path for digraphs to MP. For this purpose, we can consider a graph $S = (A; B)$ such that all nodes of S have weight 1, all arcs have color 1, $U = \{1\}$, $k = |A|$. Note that the problem of hamiltonian path for digraphs is **NP**-complete [3]. Therefore, MP is **NP**-hard. \square

4 An Explicit Reduction from MP to the Satisfiability Problem

Encoding hard problems as instances of 3SAT and solving them with efficient satisfiability algorithms widely used recently (see e.g. [4] – [8]). In this paper, we consider an explicit reduction from MP to 3SAT.

Let

$$\begin{aligned} \varphi[1] &= \bigwedge_{1 \leq i \leq k} \bigvee_{1 \leq j \leq n} x[i, j], \\ \varphi[2] &= \bigwedge_{1 \leq i \leq k,} \quad (\neg x[i, s[1]] \vee \neg x[i, s[2]]), \\ &\quad 1 \leq s[1] < s[2] \leq n \\ \varphi[3] &= \bigwedge_{1 \leq j \leq n,} \quad (\neg x[s[1], j] \vee \neg x[s[2], j]), \\ &\quad 1 \leq s[1] < s[2] \leq k \\ \varphi[4] &= \bigwedge_{1 \leq i \leq k-1,} \quad (\neg x[i, s[1]] \vee \neg x[i+1, s[2]]), \\ &\quad 1 \leq s[1] \leq n, \\ &\quad 1 \leq s[2] \leq n, \\ &\quad (v_{s[1]}, v_{s[2]}) \notin E \end{aligned}$$

$$\begin{aligned}
\varphi[5] &= \bigwedge_{1 \leq t \leq m,} (\neg x[i, s[1]] \vee \neg x[i+1, s[2]] \vee \neg x[i+2, s[3]]), \\
&\quad 1 \leq i \leq k-2, \\
&\quad 1 \leq s[1] \leq n, \\
&\quad 1 \leq s[2] \leq n, \\
&\quad 1 \leq s[3] \leq n, \\
&\quad (v_{s[1]}, v_{s[2]}) \notin E_t \vee \\
&\quad (v_{s[2]}, v_{s[3]}) \notin E_t \\
\varphi[6] &= \bigwedge_{1 \leq r \leq R,} \neg x[i, j], \\
&\quad r \notin U, \\
&\quad 1 \leq i \leq k, \\
&\quad 1 \leq j \leq n, \\
&\quad v_j \in W_r \\
\xi &= \bigwedge_{1 \leq i \leq 6} \varphi[i].
\end{aligned}$$

It is clear that ξ is a CNF. It is easy to check that ξ gives us an explicit reduction from MP to SAT. Now, to obtain an explicit reduction to 3SAT, we can use standard transformations (see e.g. [9]).

We have created a generator of natural instances for MP. We have considered our genetic algorithms OA[1] (see [10]) and OA[2] (see [11]) for SAT. For solution of MP, we have used heterogeneous cluster. Each test was runned on a cluster of at least 100 nodes. Selected experimental results are given in Table 1.

time	average	max	best
OA[1]	18.042 min	26.176 min	0.582 sec
OA[2]	6.375 min	14.53 min	11.817 sec

Table 1: Experimental results for MP.

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